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HENRY O'MALLEY, Commissioner

OYSTER-CULTURAL PROBLEMS OF CONNECTICUT

By J. S. GUTSELL
Scientific Assistant, U. S. Bureau of Fisheries

APPENDIX X TO THE REPORT OF THE U. S. COMMISSIONER OF FISHERIES FOR 1923

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That the situation in the northern oyster fields is a serious one has been evident for a number of years. In the Long Island Sound region, upon the seed production of which so much of the northern oyster industry has depended, where cultural methods had early and great development, and where oyster growing long ago became one of the big, highly organized industries, the "sets" or annual crops of young oysters have become light and irregular and production has greatly fallen off. Even the most successful growers have had to curtail their forces and equipment and reorganize on a reduced scale. If loss in volume had not in some measure been counteracted by an increase in price, many, if not all, of the concerns would have been put out of business.

From the early days of the industry up to the end of the last century, "sets" in the oyster areas along the north shore of the Sound were generally heavy and almost unfailing. At first the seed oysters obtained from these "sets" were used for planting various inshore growing or conditioning areas, particularly bays, harbors, etc., in the region. Later such plantings were extended more and more into the Sound, and finally into the deep-water, offshore areas, the use of which has made this region famous. As its reputation for vitality and growing qualities became established, Connecticut "seed" came into great demand wherever in the north there existed areas adapted to growing or conditioning oysters but where the locally produced supply was insufficient or unsatisfactory. Thus a special stimulus was given to the production of seed.

Gradually another set of factors helped to strengthen this situation and increase such demand. In the early days of almost pristine purity of the waters, the oysters of Connecticut bore an excellent reputation for edibility and were readily and profitably marketable. The principal supply and all the more highly prized varieties came from harbors, small stream-fed bays, and the lower reaches of rivers. As industrial and sewage pollution increased in these estuaries, however, the quality of the oysters deteriorated. Growing became more and more difficult. In time production was almost limited to the Sound. The Sound oysters, never having had the reputation possessed by the harbor and river oysters, suffered less in quality than the latter but failed fully to take their place in the markets. This situation, combined with the reputation of the Sound oysters as seed, helped to make the oyster industry of Connecticut more and more one of "seed" production.

[1] Appendix X to the Report of the U. S. Commissioner of Fisheries for 1923. B. F. Doc. No. 960.

An examination of the following table will show that after 1900 "sets" in this region became generally light or scattering until 1911, when an excellent "set" was obtained, and that thereafter there was only one important "set"—that of 1914. Such was the situation in the Connecticut oyster-growing region when the bureau's investigations were begun in the spring of 1917. This state of affairs, which has continued up to the present time with slight modifications, was, of course, particularly menacing to an industry so largely one of seed production. What was the explanation of this lack of set, and what could be done to restore it? Intelligently to answer either of these questions, even in part, there is required an understanding of the development or life history of the oyster, particularly the early life history, and a due appreciation of the factors, local and general, that affect its development and distribution.

Table showing the extent of oyster sets in Connecticut waters from 1885 to 1923, inclusive.[1]

Year.	Set.	Year.	Set.	Year.	Set.
1885	Good.	1898	None.[2]	1911	Good.
1886	Unknown.	1899	Excellent.	1912	None.
1887	Excellent.	1900	Fair.	1913	Do.
1888	Light.	1901	Light.	1914	Fair.
1889	Do.	1902	Poor.	1915	None.
1890	Excellent.	1903	Very poor.	1916	Do.
1891	Very good.	1904	Excellent.	1917	Do.
1892	Do.	1905	Scattering.	1918	Fair.
1893	Fair.	1906	Very poor.	1919	None.
1894	Very good.	1907	Do.	1920	Poor.
1895	Do.	1908	Scattering.	1921	Do.
1896	Good.	1909	Poor.	1922	Light.
1897	Uneven.	1910	Do.	1923	Poor.

[1] Compiled chiefly from reports of various oyster houses, and since 1917 from personal observations.
[2] It is reported that there was a good set in this year, but that it was destroyed by storms.

In its final stage the oyster is a sessile bivalve, fixed to one spot and taking from the water only such minute food as comes within the reach of the current produced by means of the wave action of its infinitely numerous cilia. In the younger stages its life is quite different.

As Brooks[2] discovered many years ago, the sexes of the oysters of the Atlantic coast of the United States (*Ostrea elongata* Solander) are contained in different individuals—not combined in one, as is the case with the European oyster, *Ostrea edulis*. The female oyster produces many millions of minute eggs or female reproductive cells; the male, countless millions of still more minute actively swimming sperms. With the warming of the water in the spring the oyster feeds more and more actively, and the development of the sexual products takes place. Finally, when these are matured, eggs and sperms are cast into the water under the influence of an increase in water temperature. If eggs and sperms are cast at the same time from oysters near one another, the sperms find the eggs and development of the oyster begins. If neighboring oysters do not spawn at the same time, union of male and female cells fails to occur and whatever spawn is cast is wasted.

[2] Brooks, W. K., "Development of the American oyster." Report of the Commissioners of Fisheries of Maryland, January, 1880 (for 1879), pp. 35–37. Annapolis.

From the fertilized egg the oyster develops rapidly into a swimming embryo containing its own nourishing material, and from that, within a day or so, depending upon the temperature, it develops into another, more vigorously swimming stage—the microscopic, actively feeding larva with a double or two-valve shell somewhat like that of a clam. This stage continues much longer than the previous one.

Although the larva's habit of occasionally settling to the bottom tends, to a limited degree, to check the influence of the tide, during these early stages the oyster is practically at its mercy. Aside from this settling habit only the back-and-forth or reciprocal action of the tide and whatever collecting or stationary effect it may produce by means of eddies prevent the larvæ from being carried hopelessly about and broadcasted, as it were, in the most wasteful and destructive manner. Finally, a very small proportion of the oysters complete the larval stage, "set" by attachment to firm, hard objects such as oyster shells, and attain the spat or first sessile stage.

Experience and the science known as ecology teach us that for any proper understanding of the life of any organism—plant or animal—we must study it in relation to its environment—organic and inorganic, dynamic and passive. The environment of the oyster, obviously, is an aquatic one, but not all aquatic environments are suitable for it. Fresh-water areas are, of course, ruled out, and so are those of full ocean saltness. Between these two extremes are the moderately salty or brackish areas. It is in such areas, which embrace so many sounds, bays, harbors, and estuaries of all sorts, that the oyster finds its proper environment; but here, again, qualifications must be made. Food organisms must be sufficiently plentiful, enemies not too abundant, the bottom neither too soft nor too shifting, the chemical content of the water such that no serious poisonous effect will be produced, and the water temperatures those to which the oyster may easily adapt itself.

That both salinity and temperature are important factors in Long Island Sound oyster cultivation is apparent from consideration of the situation. The Sound is almost the northern range limit of the oyster along the Atlantic coast of the United States. Being a very large body of water with a tremendous tidal flow from the ocean, its salinity is reduced comparatively little by the generally small if rather numerous rivers that flow into it. It therefore approaches the range limit both as to salinity and temperature. Although the salinity of the Sound is rather high for the development of oysters of the very best "meat," it by no means shows an unfavorable effect on reproduction. Summer temperatures, however, have a very important bearing in this regard.

It has long been known that water temperature is an important factor in oyster spawning, a fact which the work of the bureau's investigators has served to emphasize. This does not mean that any hard and fast rule can be laid down for the relationship between water temperature and spawning, nor does it follow that temperature is the only influence involved, but it is an observed fact that oyster spawning can be held back by low temperature and induced or "forced" by an increase in water temperature. Under natural conditions the really vigorous and extensive spawnings almost, if not quite always, are coincident with a marked rise in temperature.

Although, as before stated, no exact rule as to the effect of temperature on the spawning of oysters can be formulated, something of the relationship between the two can be given. At temperatures below 70° such spawning as occurs is almost invariably of the slow, little at a time, or dribbling sort, but under certain circumstances ripe oysters, previously deterred from spawning by low water temperatures, will spawn vigorously when a rise comes, even if this rise stops somewhat short of attaining 70°. In general, however, spawning at temperatures appreciably below 70° is of the dribbling sort, which does not produce heavy sets. If temperatures approaching 70° have been maintained sufficiently long to insure seasonal sexual maturity, but not long enough to allow the dribbling of most of the spawn, an increase to 70°, if maintained for a day or two, will produce active concerted spawning. Under similar circumstances an increase in temperature markedly above 70° will cause extremely vigorous and almost universal spawning. In northern waters abundant larvæ and "heavy" sets are produced only by these vigorous concerted spawnings.

The accompanying maps (figs. 1 and 2) make clear the historic fact that the great natural oyster areas of Connecticut were harbors, lower reaches of rivers emptying into the Sound, and sections in the Sound just off the mouths of these estuaries and so situated as to be affected by the flow from them. These were the great self-maintaining areas and the natural producers of seed oysters. As they became depleted and were turned over in greater or less measure to private enterprise they, with some extensions in the Sound, became the great private seed-producing grounds.

The principal reason for this condition is to be found in the early and high warming of the water in the estuaries. This warming produced concerted and vigorous spawning, which in turn produced vast numbers of embryos and then larvæ. Coming at an early date it gave excellent opportunity for the larvæ to develop and set and for the set to make a good growth and pass through the more delicate early stages before the September storms set in. These sets were not confined to the estuaries themselves but extended naturally some distance into the Sound. By planting shells for the larvæ to set on, oyster-culturists increased these Sound setting areas.

Under private culture, as long as conditions in the harbors and rivers made oyster growing or conditioning profitable, fairly large beds were maintained. As conditions became worse, fewer and fewer oysters were planted on the private harbor or river grounds, and those grounds that were still public became depleted. With the general passing of harbor and river production came the general failure of "sets." With the failure of "sets" came such an extended depletion of Sound areas that the chance of good "sets" from the spawning of Sound oysters was reduced. Obviously, if the Connecticut oyster industry is to be kept going, either effective estuarial spawning beds must be maintained or oyster planting in the Sound must be of such a type that reasonably good sets may occur at reasonably frequent intervals.[3]

[3] This consideration of the question takes no notice of the possible success of "artificial" set production, but even if this were developed, it is questionable how much it would benefit Connecticut with its best oyster areas so largely destroyed.

In general,[4] conditions became so bad that the planting of oysters in harbors and rivers was no longer profitable except as to such set as might be produced; so bad, in fact, that it was difficult even to maintain oyster beds in these places, and the chance of set production was very poor. Indeed, water collected in 1918 at various

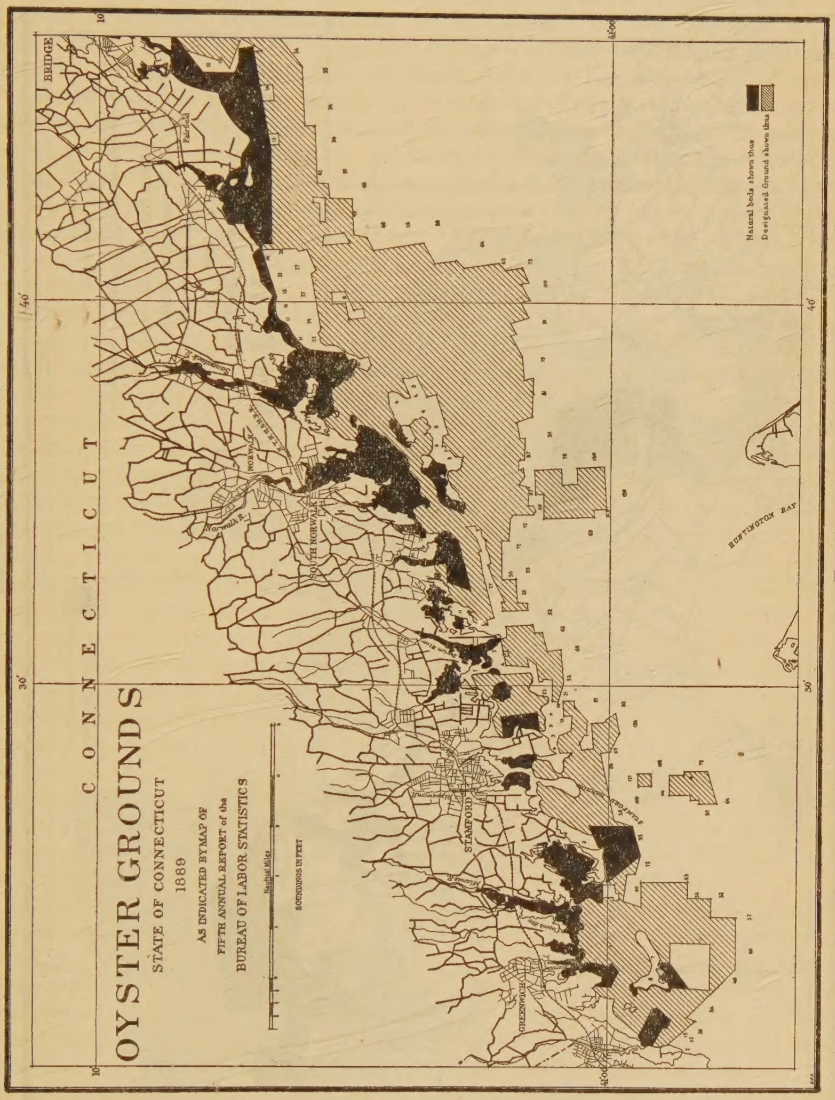

FIG. 1.

locations in one of the more highly industralized harbors was found by Dr. E. P. Churchill, formerly in charge of the bureau's oyster investigations, to be quickly fatal to oyster larvæ even when diluted one-half with unpolluted water. This means that to get any ap-

[4] New Haven is the principal exception, but even there much trouble is experienced.

preciable relief either conditions in the estuaries would have to be greatly improved or attention turned to the Sound.[5]

Improvement in harbors and estuaries is very greatly to be desired, and their restoration to conditions really favorable to oyster culture would be a wonderful boon to the oyster industry. Not

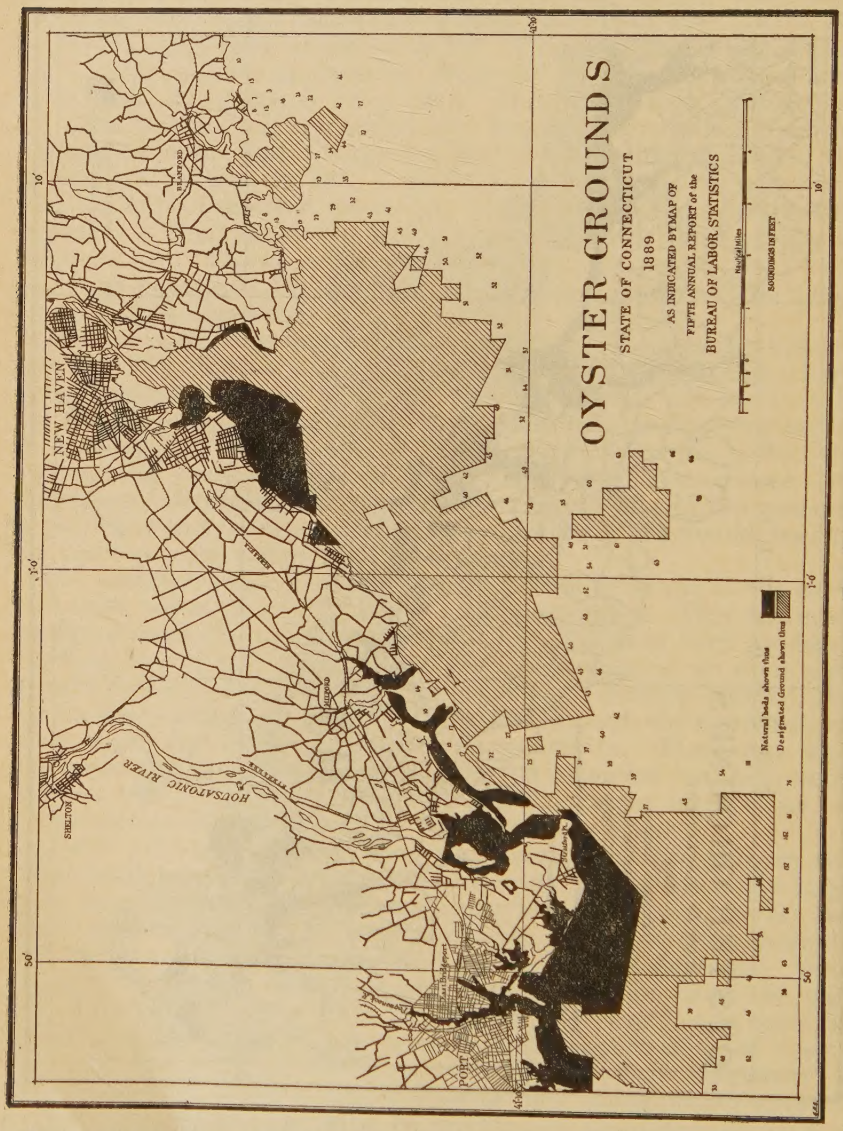

FIG. 2.

only would seed production be improved, but the finest of the growing and conditioning areas would be returned to productivity, the oyster business of the State increased, and the country's total of high-class market oysters augmented to a marked degree.

[5] See footnote 3 on p. 4.

The chief factor to be corrected in order to bring this about is trade-waste pollution. Domestic sewage pollution is, of course, undesirable, and when sufficiently great it makes necessary the transfer of oysters to pure water for cleansing. Where such pollution is excessive, it may produce such a degree of depletion of dissolved oxygen as to be harmful or even deadly to oysters or other aquatic forms. If rapid sedimentation from contact of the sewage with salt water ("salting out") occurs over an oyster bed, much damage may be wrought. Moreover, in these days of the automobile, even if trade wastes in the sense of discarded by-products of manufacture be kept from the municipal sewers, many poisonous petroleum products are inevitably present in untreated sewage. Therefore, from the standpoint of oyster production as well as from that of health, municipal sewage discharge into oyster waters should be prevented or properly controlled. However, as before stated, the principal factor to be corrected in this highly industrialized region is trade-waste pollution. Many of these trade wastes are actively poisonous to oysters or other edible forms, or to the organisms on which they feed. The prevention of the discharge of harmful trade wastes is the great problem to be solved in the restoration of the most valuable of Connecticut's oyster waters.

In order to shed light on some of the specific improvements needed, the bureau's investigators tested the effect of various important industrial pollutants[6] on oyster larvæ and spat. Doctor Churchill, in 1920, used various solutions of metallic salts, which, in strengths of 10 parts of copper, 20 parts of zinc, and 45 parts of lead per million parts of water, were quickly fatal to small oyster larvæ. He also found various dyes to be highly poisonous. More recently the author conducted experiments with salts of these heavy metals and with a few other substances to test their effect on embryos, larvæ, and spat. The results of these experiments were tested by means of "controls," in which embryos, larvæ, or spat were kept under the same conditions except that pure water, lacking the chemicals, was used. Where experiments were prolonged the water was changed from the same source, both for the controls and for the poisoning experiments, with a renewal of the chemicals for the latter. Except where otherwise indicated there was approximately 100 per cent survival in the controls. This consistent high survival shows that the loss in the poisoning experiments was due to the addition of the chemicals.

Although spat, because of their ability to remain tightly closed for hours and probably days at a time, are difficult to poison quickly, yet they are satisfactory subjects for most tests because of the ease with which they may be kept alive. In the tests of the effect of metallic salts upon spat, the copper salts have consistently proved most deadly. A copper-salt solution containing 1 part of metal per million was fatal in 5 days to 70 per cent of the spat exposed to it. A solution of slightly less than 2 parts per million was fatal in four days to all spat exposed to it. Solutions of zinc and lead salts of 10 parts of the metal per million exhibited no greater toxicity than did solutions of 1 and 2 parts of the copper per million. With

[6] Determined by the investigations of J. W. Sale, now chemist in charge, Water and Beverage Laboratory, Bureau of Chemistry, U. S. Department of Agriculture.

sulphuric acid in a 0.01 per cent solution, 18 per cent mortality occurred in 5 days. Logwood in a 0.1 gram per liter solution exhibited only a moderate fatality—25 per cent in 12 days—but was evidently more harmful than the rate of fatality indicated, for it proved so obnoxious to the spat that they remained closed a large portion of the time. Such an effect would be very harmful to oysters in any stage, and probably would be fatal to the larvæ.

Larvæ succumb to poisoning more readily than do spat, but they are much more difficult to manipulate and observe. With large larvæ, copper-salt solutions in strengths varying from 10 to 0.5 parts of copper per million, and zinc or lead salts in solutions of 10 parts of the metal per million proved fatal in less than a day. In the controls the greater portion of the larvæ lived into the second day and frequently many of them survived for several days longer.

Embryos were used in only one poisoning experiment with a copper-salt solution of 10 parts of the metal per million. In this the embryos suffered no apparent ill effects for a little over an hour. The next morning, however, all were dead and disintegrating. No marked mortality was observable at this time in the control, in which considerable numbers of the embryos lived until night.

These experiments make it clear that copper, even in very small amounts, is a serious menace to the oyster industry, and especially to that vital part of it—seed production. If anything is to be done to bring the estuaries back to their former high productivity the prevention of the discharge of copper-containing wastes should be the first step taken. Zinc, lead, strong acids, and logwood, among the substances tested, should also be guarded against. J. W. Sale, water and beverage laboratory, United States Department of Agriculture, while investigating for the bureau, found all of these substances in, or being discharged into, the waters of industrialized rivers and harbors opening into the Sound. The metals, in particular, have not only been found in the effluents from industrial plants, but have also been revealed by analyses of water samples taken from the rivers and harbors of the region. Copper, indeed, has been found in solutions of just under 0.5 parts per million where oysters formerly abounded. It is altogether probable that at some stage of the tide this strength may, on occasion, be equaled or even slightly exceeded.

Although something can be and has been accomplished by planting oysters in harbors and rivers solely for spawning purposes, yet unless the pollution of these waters can be prevented the source of any really extensive set must be sought in the Sound, where far the greater portion of the oysters is located.

In the Sound, oyster lots are roughly graded into two classes—inshore and offshore. Offshore lots frequently possess advantages over inshore lots as holding grounds, as otherwise, with the increased depth and other drawbacks, they would not be kept stocked with oysters when inshore lots are available. However, from the fundamental standpoint of seed production—that is, as a location for oysters to produce the great and early abundance of larvæ needed for "heavy" and sufficiently early sets—they are almost hopeless.

The bureau's investigations have shown[7] that the time elapsing between fertilization of the egg and setting is approximately two weeks. Another two weeks is required to bring the spat to about one-fourth of an inch in diameter. Spat should have attained this size early in September to be commercially valuable, able to withstand shifting from starfish or drill-infested grounds, or capable of withstanding the September storms. If September 7 (about the latest reasonable date) is allowed for the attainment of this size, then setting should occur by August 24 and spawning by August 10. This eliminates deep-water offshore lots, over which the bottom water warms slowly, to no very high degree, and for a brief season only, for on these active oyster spawning at such an early date is almost unknown.

With the inshore lots the story is a different one. On these, even in the colder summers, spawning begins in earnest only a little too late to be effective. In the warmer, more favorable summers it begins two weeks or more before the limit chosen. Spawning on these lots has, therefore, in so far as time is concerned, an excellent chance to be effective. For it really to be effective, however, large plantings of oysters should be maintained on inshore lots—that is, lots within three-quarters of a mile or even a mile of shore. Although the danger from storms prevents the use of quite a portion of the inshore lots, especially those nearest shore and therefore most desirable for the location of oysters for spawning, many of them are available. To keep these well stocked, all planters should cooperate so that one planter may not feel that he is supplying the set for somebody else instead of for himself. With such action properly and continuously carried out, there is, from the data available, substantial evidence that improved sets would result.

CONCLUSIONS.

The chief conclusions as to improvement in oyster production in Connecticut are as follows:

1. For the restoration of the Connecticut oyster industry, in both quantity and quality, to its former productivity, it will be necessary greatly to improve water conditions, especially in the almost barren harbors and rivers from which formerly came the more highly prized oysters and in which were produced the vast numbers of oyster larvæ so largely responsible for the "heavy sets" of the past. To accomplish this, municipal sewage discharge should be controlled, and the discharge of harmful trade wastes, especially those from copper and brass works, should be prevented.

2. Until a change of conditions in estuaries makes oyster growing in them generally and extensively profitable, any great improvement by methods available at present must be produced by increased "sets" derived from the spawning of Sound oysters. Oysters on offshore Sound lots spawn too late to be effective. On the other hand,

[7] Annual manuscript reports of Doctor Churchill and the author. Also the work of Drs. Julius and T. C. Nelson (see report of the department of biology of the New Jersey Agricultural College Experiment Station, New Brunswick, N. J., for 1922, p. 330), and experiments by H. F. Prytherch, of the Bureau of Fisheries.

oysters on inshore lots (those within three-quarters of a mile or even a mile of shore) quite frequently spawn early enough to produce usable and hardy set. Therefore special and concerted action should be taken by the growers to keep such of the inshore grounds as are at all satisfactory well stocked with oysters. The evidence strongly indicates that by this means an improvement—small in comparison to that which would result from a thorough reestablishment of harbor and river growing, but still a considerable and much needed one—could be brought about.

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